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Warehouse Re-Layout for a Third-Party Logistics Provider Based on Shipping Patterns Using the Apriori Algorithm

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Abstract

Warehouse operations face challenges that affect efficiency. PT ABC, a third-party logistics provider, has been experiencing these issues due to an unstructured warehouse layout. It leads to inefficient movement and delayed deliveries. This study aims to re-design the warehouse layout of PT ABC based on shipping patterns using the apriori algorithm. Shipment data from January to June 2024 was analyzed using the apriori algorithm with a minimum support of 30% and a confidence level of 50% to find frequently shipped item combinations. One of the strong associations found was between "Mechanical Components" and "Spare Parts," with a lift value of 1.68. Based on the results, a proposed layout was developed by considering both the FSN (Fast, Slow, Non-moving) classification and apriori findings. The effectiveness of the new layout was evaluated using rectilinear distance calculations, which showed a reduction in total item movement distance from 45,952 meters to 44,343 meters.
Keywords: *Warehouse Layout; Third Party Logistics; Apriori Algorithm*

Abstrak

Permasalahan pada pengelolaan gudang dapat berdampak pada efisiensi operasional. PT ABC sebagai perusahaan *third party logistic* (3PL) menghadapi permasalahan dalam *layout* yang tidak beraturan. Permasalahan utama yang dihadapi adalah penyimpanan barang yang tidak terstruktur yang menyebabkan meningkatnya jarak perpindahan barang dan keterlambatan pengiriman. Penelitian ini bertujuan untuk merancang ulang tata letak gudang PT ABC berdasarkan pola pengiriman barang menggunakan algoritma apriori. Data pengiriman selama Januari–Juni 2024 dianalisis menggunakan algoritma apriori dengan minimum support 30% dan minimum confidence 50% untuk menemukan pola asosiasi item yang sering dikirim bersamaan. Hasilnya menunjukkan pasangan seperti "Komponen Mekanik–Suku Cadang" memiliki nilai lift sebesar 1,68 yang menandakan asosiasi kuat. Berdasarkan hasil tersebut, disusun usulan relayout gudang dengan mempertimbangkan klasifikasi FSN (*Fast-Slow-Nonmoving*) dan hasil algoritma apriori. Efektivitas rancangan dievaluasi melalui pengukuran jarak menggunakan metode rectilinear yang menunjukkan pengurangan total jarak perpindahan dari 45.952 meter menjadi 44.343 meter.
Kata-kata kunci: *Tata Letak Gudang; Third Party Logistics; Algoritma Apriori*

1. Introduction

Warehouse operations play a strategic role in maintaining the smooth flow of the supply chain, as they serve not only as storage facilities but also as hubs for managing the flow of goods to ensure fast and efficient distribution processes [1]. According to Naomi and Fauziah (2023), warehouse management is the process of optimizing a warehouse's utilization, location, product picking speed, loading/unloading speed, product flow throughout the facility, receiving procedures, product selection, and work equipment. The efficiency of a warehouse layout directly influences picking time and operational productivity [2]. One significant contribution to operational efficiency is a well-designed warehouse layout scheme [3]. Furthermore, a proper designed layout can reduce material handling time by up to 25%, underscoring the critical importance of layout planning in supporting operational performance [4].

However, many third-party logistics (3PL) provider companies still face challenges related to unstructured storage. Goods are stored randomly without standard rules, leading to long travel distances, extended picking times, and potential delivery delays at warehouse, especially at PT ABC. This issue demonstrates the need for a data-driven approach to re-design the warehouse layout. An optimal warehousing system can utilize storage space efficiently, thereby increasing space utilization [5].

Previous research indicates that data mining techniques can be utilized to optimize storage layout configurations. For instance, studies by Muchlis et. al. (2021) successfully improved product arrangement efficiency by implementing the apriori algorithm [6], [7]. Similarly, findings from previous study confirmed that positioning items based on frequent picking combinations expedites storage retrieval in material warehouses. Nevertheless, existing literature predominantly concentrates on the retail sector [8], [9]. Nevertheless, most of the existing studies have focused on the retail sector, whereas the application of the apriori algorithm integrated with FSN classification (fast-moving, slow-moving, and non-moving) in 3PL warehouses is still rarely explored.

This research aims to re-design the warehouse layout of PT ABC by utilizing the apriori algorithm to analyze product shipping patterns, then combined it with product movement using the FSN classification. The layout improvement is evaluated using the rectilinear distance model to measure the impact of the improvement on operational efficiency.

The contribution of this research lies in the integration of the apriori algorithm with the FSN classification approach within a 3PL warehouse. It is expected that this integration will not only reduce goods travel distance but also provide a strategic foundation for the company to enhance distribution efficiency and operational competitiveness.

2. Methods

This study employed a quantitative approach using data mining methods to analyze shipment patterns and re-design warehouse layout. The research was conducted at the warehouse of PT ABC, a third-party logistics service provider. The data utilized comprises six months historical shipment data from January to June 2024, encompassing product type, shipment frequency, and demand volume.

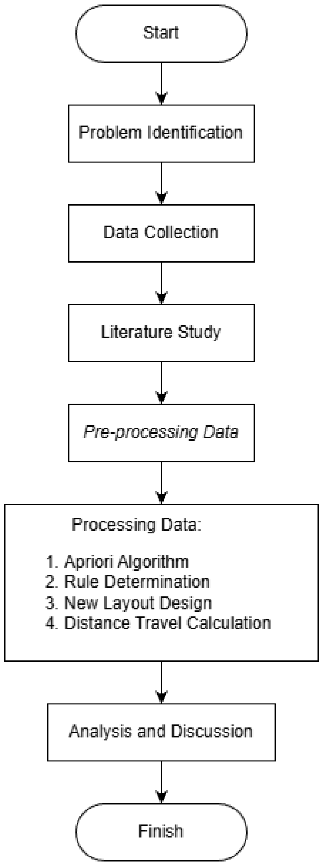

Figure 1. Research Flowchart

The analysis was performed using the apriori algorithm to discover inter-item relationships (association rule mining). The parameters used were a minimum support of 0.30 and a minimum confidence of 0.50, in accordance with the warehouse data characteristics. The results, in the form of frequent itemset with the highest lift values, served as the basis for product grouping in the new layout design. Additionally, product movement classification was conducted using the FSN classification to determine placement priority. Implementation of the apriori algorithm in this study uses the "mlxtend" library in Python, which automatically performs all stages of the algorithm based on the theoretical pseudocode. It begins with generating frequent itemsets, forming candidate combinations, and evaluating association rules based on support and confidence values. Thus, this implementation is consistent with the theoretical procedures of the apriori algorithm. The pseudocode of the apriori algorithm can be seen in Figure 2 [10].

```
F_1 = {frequent items of size 1};
for (k = 1; F_k !=ϕ; k++) do begin
    C_{k+1} = apriori-gen(F_k); // New candidates generated from F_k
    for all transactions t in database do begin
        C'_t = subset (C_{k+1},t); // Candidates contained in t
        for all candidate c ∈ C'_t do
            c.count++; // Increment the count of all candidates
            in C_{k+1} that are contained in t
        end
        F_{k+1} = {C ∈ C_{k+1} | c.count ≥ minimum suport}
        //Candidates in C_{k+1} with minimum support
    end
end
Answer ∪_k F_k ;
```

Figure 2. Apriori Algorithm Pseudocode

The layout re-design utilized a proximity-based placement approach (association-based re-layout), considering combinations of items frequently shipped together. The design evaluation employed the rectilinear distance method to calculate the total travel distance for both the initial and proposed layouts. A comparison of the two results was used to measure efficiency improvement.

3. Results and Discussion

Data processing commenced with FSN classification using the cumulative consumption method to categorize items into Fast-moving, Slow-moving, and Non-moving groups. Subsequently, the apriori algorithm was applied through data selection, data cleaning, and data transformation. Parameter has set at a minimum support of 30% and a minimum confidence of 50% to derive association patterns among items. In this context, support measures the proportion of transactions containing a specific combination of items. Confidence measures the probability of the consequent item's appearance given the antecedent, while lift indicates the strength of the association compared to chance. The association rules and FSN classification were then utilized to design a proposed layout. This proposed layout, alongside the initial layout, was evaluated using the rectilinear distance method to calculate the total material handling distance.

3.1. FSN Classification

The warehouse layout re-design process begins with grouping items using the FSN classification. This classification plays a crucial role in establishing item arrangement priorities by identifying the movement level of each item based on its shipping frequency over a specific period. Items are categorized based on cumulative consumption as shown in Table 1.

Table 1. FSN Classification: An Overview

Category	Qty	Items
Fast-moving	10	Shell Spirax S4, Aluminium Sulphate
Slow-moving	27	Fastener, Shell Gadus
Non-moving	15	Special equipment

3.2. Apriori Algorithm

The apriori algorithm generated 42 association rules, with three rules meeting the minimum thresholds of 30% support, 50% confidence, and a lift value > 1. As presented in Table 1, the association rule {Mechanical Component, Spare Part} → {Fastener} demonstrates a lift value of 1.68. This indicates that the likelihood of a Fastener being present in a transaction containing both Mechanical Component and Spare Part is 1.68 times greater than if its occurrence were statistically independent or purely random.

Table 2. Top-Lift Association Rules

Antecedents	*Consequents*	*Support*	*Confidence*	*Lift*
Spare Parts, Mechanical Components	Fastener	0,31	0,68	1,68
Fastener	Spare Parts, Mechanical Components	0,31	0,77	1,68
Spare Parts, Fastener	Mechanical Components	0,31	0,81	1,60

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Mechanical Components	Spare Parts, Fastener	0,31	0,62	1,60
Mechanical Components	Fastener	0,32	0,64	1,58

3.3. Travel Distance Evaluation

A comparison between the initial and proposed layouts indicates a reduction in travel distance. Developing the layout based on FSN classification and apriori analysis results requires quantitative validation, which is through calculating material travel distance to measure the design's effectiveness. Therefore, measurement was conducted using the rectilinear distance method, which calculates the total distance by summing the differences between the horizontal (X) and vertical (Y) coordinates of two points.

The following is a sample distance calculation for block 1 in the initial layout. Material Aluminum Sulfate, categorized under Chemicals & Substances, is placed in blocks K17–K23. Let "i" represent blocks K17–K23 and "j" represent In/Out, which is the warehouse door as the starting point (0,0) located at the bottom-left corner. Thus, $Xi = 4.8 + (1 \times 16) + (8 / 2) = 24.8$ meters, and $Yi = 2.3 + 2.5 + 2.5 + 2.3 + (2.5 / 2) = 10.85$ meters. For point "j", $Xj = 0$ and $Yj = 2.3 + 2.5 + 2.5 + 2.3 + (3.6 / 2) = 11.4$ meters. The difference in horizontal (X) and vertical (Y) coordinates yields a rectilinear distance of 25.35 meters. This value is then multiplied by its frequency of 60, resulting in a total travel distance of 1,521 meters.

Table 3. Prior Distance Calculation (Before Re-layout)

Block	Xi	Yi	Xj	Yj	|Xi-Xj|	|Yi-Yj|	Distance (meter)	Freq.	Final Distance
K11	15,3	10,85	0	11,4	15,3	0,55	15,85	36	570,6
K11	15,3	10,85	0	11,4	15,3	0,55	15,85	11	174,35
K10	16,3	10,85	0	11,4	16,3	0,55	16,85	16	269,6
K10	16,3	10,85	0	11,4	16,3	0,55	16,85	20	337

Table 4. Post Distance Calculation (After Re-layout)

Block	Xi	Yi	Xj	Yj	|Xi-Xj|	|Yi-Yj|	Distance (meter)	Freq.	Final Distance
M9	13,3	3,55	0	4,1	13,3	0,55	13,85	36	498,6
M13	17,3	3,55	0	4,1	17,3	0,55	17,85	11	196,35

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Block	Xi	Yi	Xj	Yj	|Xi-Xj|	|Yi-Yj|	Distance (meter)	Freq.	Final Distance
M10	14,3	3,55	0	4,1	14,3	0,55	14,85	16	237,6
M9	13,3	3,55	0	4,1	13,3	0,55	13,85	20	277

3.4. Warehouse Re-layout Design

The association data and FSN classification were used as the basis for layout re-design. Fast-moving items were placed in the blocks closest to the distribution path, while items with strong associations were grouped in adjacent areas.

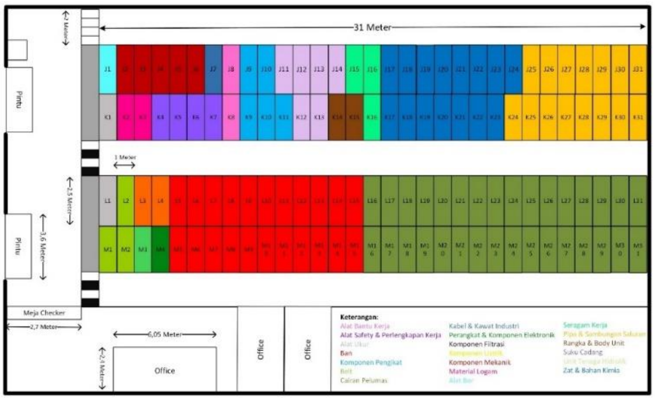

Figure 3. Initial Layout Design

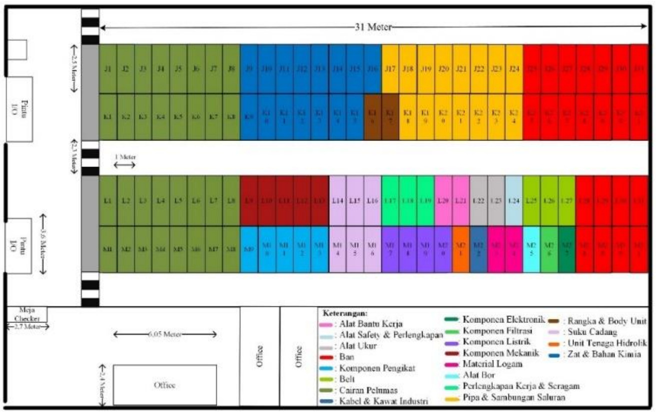

Figure 4. Layout Design Improvement

The top three rules demonstrate high confidence (0.95–0.97) with a lift above 1.25, indicating a significant association between the items **[11].** These values suggest that spare parts are almost always ordered together with fasteners and mechanical components, which is logical given that all three are commonly used in unit maintenance. This finding aligns with the study by Muchlis et. al. (2021), which emphasizes the use of association rule mining to identify complementary items in warehouse management. The result of association rules was subsequently used as the basis for item clustering in the proposed layout (Figure 2) **[6]**.

Fast-moving items like Shell Spirax S4 are located strategically near distribution channels to reduce travel time, whereas slow-moving and non-moving inventory is stored in back areas. This strategy is consistent to advocate frequency-based placement to improve operational efficiency [7].

The layout re-design resulted in a 3.5% reduction in travel distance. Although this figure may seem modest, its cumulative impact on the warehouse's monthly operational volume is substantial. This limited reduction was achievable because the initial layout was already quite dense, leaving relatively narrow room for optimization. This finding aligns with that of Hassan (2010), who states that layout improvements based on item grouping can enhance warehouse throughput. The result is also consistent with the research by Datumaya et al. (2021), which found operational time savings through layout optimization based on association patterns **[4], [8].**

From a practical standpoint, these results provide a basis for PT ABC to implement a data-driven layout to accelerate picking time and improve productivity. Theoretically, the integration of the apriori algorithm and FSN analysis extends the study of data mining-based layout design within the context of third-party logistics.

4. Conclusion

Based on the research findings and conducted analysis, it can be concluded that the implementation of the apriori algorithm in processing shipping data at PT ABC has successfully achieved both primary objectives of this study. The apriori algorithm successfully identified association patterns among items frequently ordered together, generating robust support, confidence, and lift values as the basis for establishing inter-item relationships. This process was utilized by data analytics processing and reinforced through manual verification using a mathematical model. The results from both approaches yielded identical values, thereby validating the method's accuracy both mathematically and in its practical implementation.

The algorithm's output was applied to re-design the warehouse layout. Items with strong associative relationships were placed in proximate locations to minimize travel distance. Measurement using the rectilinear distance method indicated a reduction in total travel distance: from an initial 45.952 meters to 44.343 meters after the apriori-based re-design was implemented. The proposed apriori-driven layout proves effective in improving storage space utilization and supporting a more structured and efficient workflow.

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